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(54) NEUTRON MEASURING TECHNIQUE FOR INVESTIGATING EARTH FORMATIONS

(71) We, SCHLUMBERGER INLAND SERVICES, INC., (a corporation organized and existing under the laws of Panama) 19 Berkeley Street, London, W.C.2, Great Britain, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to borehole logging techniques and, more particularly, to an earth formation porosity logging apparatus that combines signals from two detectors in response to the neutrons emitted from individual respective sources, and the like.

Earth formation porosity or hydrogen concentration data frequently provide the oil industry with information about the potential hydrocarbon production that can be expected from a borehole. Ideally, these data can be acquired through a "sonde" or logging tool that traverses the borehole. A source within the tool emits neutrons that scatter through the adjacent formation. These neutrons lose energy as a consequence of neutron interactions, or collisions, with the nuclei of the constituent formation materials. These energy losses are, to an important extent, a reflection of the relative porosity and apparent abundance of hydrogen within the formation under study.

Some of these lower energy neutrons, after a number of scattering collisions, find their way back to the logging tool and are registered in a neutron detector that is vertically spaced from the emitting source. In the absence of perturbing influences, the signal from the detector provides a measure of the earth formation porosity. These are factors, however, that may degrade or alter the basic measurement. For example, the fluid or mud that often is used to control pressure within the borehole and to flush out the drill cuttings frequently imposes a strong influence on the basic neutron spatial distribution.

Illustratively, the hydrostatic mud pressure in the borehole is slightly greater than the natural pressure within the formation. This pressure differential not only prevents formation fluids from discharging into the well, but also causes the liquid constituents in the mud to seep into the formation and deposit a film or residue of solid matter on the borehole wall. This residue, or mudcake, affects the spatial distribution of the low energy neutrons to a degree that often obscures the characteristics of the formation and thus degrades the validity of the neutron log.

Clearly, there is a need for an improved mudcake correction technique.

In accordance with one aspect of the invention, a method of investigating earth formations traversed by a borehole having solid matter along at least a portion of the wall thereof comprises the steps of: emitting neutrons of relatively high energy at successive levels in the borehole, detecting radiations resulting from said high energy neutrons at relatively long spacings from the levels at which they are emitted to produce signals functionally related to a characteristic of the earth formation, emitting neutrons of relatively low fixed energy at sucessive levels in the borehole selected to obtain a slowing down length in the solid matter before reaching thermal energy that is of the order of magnitude of the typical thickness of the solid matter, and, in response to radiation resulting from said low energy neutrons and detected at relatively

short spacings from the levels at which said low energy neutrons are emitted, producing indications representing a correction of said formation characteristic to account for said solid matter.

In accordance with another aspect of the invention, apparatus for investigating earth formations traversed by a borehole having solid matter along at least a portion of the wall thereof, comprises: a source of relatively high energy neutrons; first detector means at a relatively long longitudinal spacing from said high energy source and responsive to radiation resulting from said high energy neutrons for producing first signals functionally related to a formation characteristic; a source of fixed relatively low energy nuetrons having a slowing down length before reaching thermal energy that is of the order of magnitude of a typical thickness of solid matter expected in boreholes to be investigated; and second detector means at a relatively short longitudinal spacing from said low energy source and responsive to radiation resulting from said low energy neutrons for producing second signals functionally related to a parameter of said solid matter to provide correction for the disturbing effect of said solid matter on said first signals.

In accordance with yet another aspect of the invention, a method for investigating an earth formation traversed by a borehole having a layer of solid material along at least a portion of the wall thereof, comprises: deriving one measurmeent representative of the diffusion through this layer of material and the formation of neutrons having an initially high energy, deriving a second measurement primarily representative of the diffusion through this layer of material of neutrons having an initially relatively low energy as compared to that of said high energy neutrons, and modifying said one measurement by combining with said second measurement to produce one output measurement representative of a characteristic of the earth formation.

An improved mudcake correction is obtained through the addition of a second or auxiliary neutron source and detector to a neutron logging tool. More specifically, the auxiliary or supplementary source emits neutrons that are characterised by a low energy in order to increase probability for neutron interaction within the mudcake. For example, a source suitable in this connection will emit neutrons that have a slowing down length that is of the order of magnitude of the thickness of a typical mudcake, or a slowing down length that is appreciably less than the length characterising the neutrons emitted from the primary source. Because the slowing down length of primary source neutrons in most formations is about 10 to 30 cm, an auxiliary neutron source in accordance with the invention will provide neutrons characterized by a length of about 3 to 10 cm, depending on the mudcake quality. In order to enhance the quality of mudcake observation, the auxiliary detector is positioned, in relation to the supplementary source, to respond almost exclusively to those neutrons that are emitted from that source.

Preferably, the auxiliary detector is further limited in response to epithermal neutrons, i.e., those neutrons that have energies greater than the average thermal kinetic energy of the molecules in the scattering medium. This energy limitation is imposed because neutrons that are in thermal equilibrium are affected by extraneous properties of the mudcake, rather than by the significant characteristics of the mudcake, as for example, the layer thickness and porosity.

Sources of low energy neutrons, suitable for use in the invention, are available through the reactions of lithium to the alpha particles that are naturally emitted from plutonium and beryllium to the photons emitted from antimony. These combinations produce neutrons of average energy about 240 KeV, and photoneutrons of about 25 KeV, respectively, energies so low that probability of interaction with the material very close to the borehole wall is quite high. By contrast, the neutrons used conventionally as the principal source, for sampling the earth formation, have an average energy of about 3 or 4 MeV. By choosing a low energy source for the auxiliary investigation, and thus effectively limiting the depth of neutron investigation to the mudcake and its immediate surroundings, the number of epithermal neutrons from this source that find their way back to the auxiliary detector generally reflects the significant mudcake features.

A further characteristic of the invention provides a circuit that automatically combines signals from the auxiliary neutron detector and the signals from another detector or detectors that are acquired during the same or during a different logging run. Preferably, this circuit converts all of the signals into an output that is related to porosity or some other useful earth formation parameter.

More particularly, the auxiliary epithermal neutron detector and neutron source are relatively closely spaced in a logging tool housing. Within the same housing, or in another sidewall skid that may be attached to the same tool, a substantially higher average energy neutron source (americum-beryllium or plutonium-beryllium, for example) is spaced about fifteen or more inches from an associated principal neutron

detector. This latter source and detector combination explores the formation as well as the mudcake. In this regard, the signal from the detector associated with high energy neutron source is representative of the mudcake and the formation, while the auxiliary detector signal predominantly characterizes the mudcake. The computation system contrasts the signals from both of these detectors to eliminate mudcake effects and thereby produce an output that is more closely related to the actual formation porosity that the output of the principal detector, alone.

For improved neutron source handling efficiency, especially in arduous field conditions, the two neutron energy sources that characterize the invention can be provided with one capsule. In this manner, moreover, the need to handle two individual neutron sources in the field is eliminated, and thus the potential for injury or damage that might result from somewhat longer radiation exposure is essentially halved. Further, this arrangement permits a reduction in the length of the sidewall skid, thus allowing the skid to more closely follow the contour of the borehole wall.

For a better understanding of the present invention, reference is had to the following description taken in connection with the accompanying drawing, the scope of the invention being pointed out in the appended claims.

Figure 1 is a schematic diagram of a logging tool exemplifying principles of the invention;

Figure 2 is a generalized graph of the responses that characterize the detectors shown in the illustrative embodiment of the invention;

Figure 3 is a generalized graph of the neutron density distribution as a function of distance from the source in a further embodiment of the invention; and

Figure 4 is an illustrative embodiment of encapsulated neutron emitters in accordance with an aspect of the invention.

For a more complete appreciation of the invention, Figure 1 shows a logging tool. The tool includes a fluid-tight housing 10 that is lowered into and drawn upwardly through a borehole 11 which has been drilled through an earth formation 12. Illustratively, the borehole 11 is filled with a drilling mud 13. Vertical movement of the housing 10 is controlled through an armored cable 14 and a winch (not shown) in the earth's surface. Measurement equipment (also not shown) associated with the winch provides an indication of the depth of the housing 10 within the borehole 11. In this manner, a log of some characteristic earth formation parameter is produced as a function of the borehole depth.

In order, for example, to measure more accurately the porosity of the earth formation 12, the housing 10 is urged against a film or layer of mud or mudcake 15 on one side of the borehole 11. The force urging the housing 10 against the mudcake 15 is applied through a bowspring 16. Other suitable eccentering means, for instance a spring-loaded hydraulic system, also can be used for this purpose.

A neutron source 17 is positioned in the lowermost portion of the housing 10, preferably on the side of the housing that engages the mudcake 15. For porosity logging purposes, a mechanical mixture of beryllium and one of the plutonium isotopes (plutonium 238 or plutonium 239, for example) in sufficient quantity to provide a 10^7 neutrons per second source has been found suitable.

Because the neutrons emitted from sources of this type have an average energy of about 4 million electron volts (MeV), a high energy neutron reflector 20 is interposed between the source 17 and those portions of the housing 10 that are not pressed against the mudcake 15. Preferably, the reflector 20 is formed of a material that has a large scattering probability or cross section for high energy neutrons. Copper or steel are adequate for this purpose.

The reflector 20 redirects toward the formation 12 those neutrons that are emitted from the source 17 in a direction that tends to take them away from the adjacent portion of the borehole wall. The reflector 20 prevents neutrons from being absorbed in the drilling mud 13 and thus conserves neutrons to increase the statistical validity of the detector signal as subsequently described.

In accordance with one aspect of the invention, a supplementary or auxiliary neutron source 21 is positioned within the housing 10 and adjacent to the housing side that is pressed into contact with the borehole wall. The source 21, moreover, is in general vertical alignment with the neutron source 17. The neutrons emitted from the source 21 are of appreciably lower energy than those emitted from the source 17. As an illustrative embodiment, the 240 KeV neutrons that characterize the plutonium-lithium source are especially well suited to the shallow penetration required for sampling the influence of the mudcake 15. The auxiliary neutron source 21 also can be equipped with a neutron reflector or scattering shield (not shown) for the same purpose as that which was described in connection with the reflector 20.

A neutron detector 22 is positioned within the housing 10. The detector 22 preferably has a small active volume that is filled with a neutron-responsive gas, e.g., boron trifluoride or helium 3 (He^3). Typically, the detector 22 responds to the

neutrons from the auxiliary source 21 that make their way back toward the housing 10 by scattering collisions in the mudcake 15. Charged particles are produced in the counter gas through neutron reactions. These reactions produce ionization which establishes an electrical charge in an output conductor 23.

In order to limit the sensitivity of the detector 22 to epithermal neutrons and thereby overcome the effect of saline water on the observed neutron distribution, the detector 22 is encased in a sheath 24, typically of cadmium. The cadmium essentially absorbs all of the incident thermal neutrons to prevent them from entering the active volume of the detector 22. Thus, the response from the detector 22 represents only those neutrons that make their way back to the housing 10 with energies greater than thermal.

The response of the detector 22 is further reduced through neutron shielding 25 that is interposed between the detector 24 and those portions of the housing 10 that are not in contact with the mudcake 15. The neutron shield 25, formed of boron carbide for example, absorbs substantially all of the otherwise detectable neutrons that approach the detector 24 from directions other than the portion of the mudcake 15 or borehole wall that is in engagement with the housing 10. In this manner, the influence of the borehole fluid on the neutron distribution that is registered in the detector 22 is to a larger degree reduced in significance.

Signals from the detector 22, sent through the output conductor 23, are conditioned in a downhole processing circuit 26 for transmission to the earth's surface through an insulated conductor 27 in the armored cable 14. Typically, the downhole processing circuit 26 includes scaling circuits to reduce the detector pulses by a constant divisor and ease the signal transmission burden on the cable 14. The circuit also preferably includes one or more pulse height discriminators to eliminate noise, and an amplification system to enable the scaler output pulses to travel through several thousand feet of the cable 14, and arrive at the earth's surface in a recognizable condition.

A second neutron detector 30 is spaced vertically above the high average neutron energy source 17 by about fifteen inches. Typically, the detector 30 comprises a tube filled with He^3 to a pressure of about ten atmospheres when measured at standard conditions.

For essentially the same reasons as those which were advanced in connection with the detector 22, the detector 30 is positioned within the housing 10 against the housing side that is urged into contact with the mudcake 15. The detector 30 also is encased in a thermal neutron absorption sheath 31 and is partially encircled by a neutron absorbing shield 32 that is interposed between the detcetor 30 and those portions of the housing that are not pressed against the mudcake 15.

The detector 30 responds to epithermal neutrons that are scattered from the formation 12 through the generation of charge pulses in an output conductor 33. These pulses are received in the downhole processing circuit 26. The circuit 26 processes or conditions the pulses for transmission to the earth's surface through an insulated conductor 34 in the armored cable 14.

On the earth's surface, the signals from the detectors 22 and 30 in the conductors 27 and 34, respectively, are received in a pulse processing circuit 35 that distinguishes the respective signals from electrical noise induced in the cable 14 during transmission, and reconditions these pulses for further manipulation or processing.

The reconditioned signals from the detector 22 are sent from the pulse processing circuit 35, through a conductor 36 to a pulse counting rate meter 37. The meter 37 integrates the input pulses to produce an output signal in a conductor 40 that is representative of the mean value of the time distribution of these pulses (detector counts per second, for example). In a similar manner, signals from the detector 30 are sent from the processing circuit 35 through a conductor 41, to a neutron detector pulse counting rate meter 42.

The count rate signal from the meter 42 is sent through a conductor 43 to a function former circuit 44. The function former circuit 44 combines the count rate from the detector 22, predominantly influenced by the mudcake, that is received in the form of the rate signal in the conductor 40, with the porosity and mudcake count rate from the detector 30 in the conductor 43, in order to identify the porosity of the formation 12.

Illustratively, for a specific formation mineral composition, the function former circuit 44 combines the count rates that characterize the detectors 22 and 30 according to the generalized relation that is shown in Fig. 2. In this connection, for a limestone mineral composition, a count rate A from the detector 30 and the rate meter 42, and count rate B from the detector 22 and the associated rate meter 37 identify a point 45. The point 45 corresponds to a formation porosity of about eleven porosity units and a mudcake parameter or quality factor slightly less than 1. This quality factor is an arbitrarily assigned value that is based on empirically developed data that combine, for example, the mudcake thickness and mudcake porosity in order

to provide a compensatory relation for a particular logging environment. These relations, of the sort illustrated in Fig. 2, may be derived, for example, through extensive tests executed in formations of known porosity and mineral composition as well as with known mudcake characteristics. These observed data then are compiled in the form of graphs or data tables which, for a given mineral, will relate specific porosity and mudcake quality combinations to particular detector count rates. Alternatively, or as a supplement, these data can be acquired through tests conducted in laboratory formations of established characteristics and with simulated mudcakes.

Turning once more to Fig. 1, a typical function former circuit capable of producing in electrical response the properties of the graph in Fig. 2, preferably comprises an operational amplifier and a diode-resistance feedback network. Responses for the function former circuit 44 that are appropriate to different formation mineral compositions; as for example, dolomite and sandstone, can be chosen through a manual selection switch 46. Typically, the switch 46 will permit the diode-resistance feedback network appropriate to the mineral composition of the formation undergoing irradiation to be coupled to the operational amplifier in order to establish output signal that are commensurate with the input signals. The specific earth formation mineral composition that is under observation in a particular situation can be determined, for example, through an examination of drill cuttings.

Automatic techniques can be used to supplant the mineral selection switch 46. For instance, the signals from the detectors 22 and 30 can be stored on tape for subsequent manipulation, or if convenient, applied directly to a digital computer that combines other diverse logging signals to produce output data of industrial importance.

Continuing with Fig. 1, the mudcake parameter signal is sent through a conductor 47 to a recorder 48. The porosity signal also is sent to the recorder 48 through a conductor 50 in order to provide a record of mudcake parameter and earth formation porosity as a function of borehole depth. This record, although often presented in the form of a graph or chart, also can be stored on magnetic or paper tape, punched cards, and the like, for further processing as a part of a larger log analysis system as hereinbefore described in connection with the signals from the detectors 22 and 30.

A log of the mudcake parameter and earth formation porosity also provides a useful indication of the degree to which the pores within the formation 12 are interconnected. This information, usually known as permeability, is a measure of the relative ease with which fluids can be extracted from the formation. For instance, in some cases, a thick mudcake indicates a highly permeable rock structure because the mud filtrate is able to invade the formation with apparent ease and deposit a relatively thick residue on the borehole wall. Accordingly, a thick mudcake adjacent to a highly porous formation may be of industrial importance as a zone of further investigation for potential hydrocarbon production.

The relative positions of the auxiliary source 21 and the associated detector 22 with respect to the positions of the source 17 and the detector 30, can be chosen in accordance with specific circumstances and design optimization criteria. For instance, neutron source 21 can be secured in a convenient location within the housing 12, in a separate skid, or in a different logging tool for use in a separate logging run. The strength of the auxiliary source 21 can be optimized for specific logging conditions.

Typically, the separation between the auxiliary detector 22 and the neutron source 17 should be sufficient to reduce to a negligible amount the count in that detector from neutrons that originate at the source 17. In a similar manner, the detector 30 should be spaced far enough from the auxiliary source 21 to produce a minimum signal in response to the neutrons that are attributable to that source. Actual separations between sources and the detectors can be determined through optimization for specific mudcake and porosity conditions. Illustratively, one of the sources can be removed and the detector position within the sonde can be varied until the undesired neutron signal reaches a sufficiently small value. The removed source can be replaced and the other source taken from the tool while the position of the remaining detector is varied to determine the separation that is appropriate to a sufficiently small undesired neutron signal.

In operation, a neutron 51 is emitted from the source 17 and collides with a nucleus in the earth formation 12. As a consequence of the collision, the neutron transfers some of its energy to the nucleus and is scattered in a new direction. It is then scattered again, with energy loss. This process is repeated many times. Eventually, incident neutron 51 enters the detector 30 and is registered as an individual event. The number of these events tends to characterize, for example, the hydrogen concentration or the porosity of the formation 12. Another neutron 52, also emitted from the source 17, eventually diffuses into the active volume of the detector 30 principally through collisions with mudcake nuclei. Consequently, in the illustrative example, the signal genera-

ted by the detector 30 combines formation and mudcake information.

Because of the low source emission energy, however, a neutron 53 from the auxiliary source 21 penetrates not much deeper than the mudcake 15. The neutron 53 is multiply scattered back toward the active volume of the supplementary detector 22. Clearly, the signal from the detector 22 is limited almost entirely to mudcake information. In accordance with a feature of the invention, these two detector signals are combined to segregate the porosity contribution from the composite mudcake and porosity output that characterizes the neutron detector 30.

As shown in Fig. 3, the low energy neutron emitting source, characterizing curve 60, and high energy neutron emitting source, illustrated by curve 61, can be combined in a single capsule. The epithermal neutron distributions as a function of distance from the combine sources is typified in the figure of the drawing. It should be noted that the actual neutron distribution can vary as a function of many factors. For instance, observed neutron energy ranges, borehole and mudcake characteristics all have a bearing on the neutron-distance distribution.

Combining neutron emitters in this manner eliminates the need for two source capsules. This reduces the radiation hazard inherent in personnel exposure that would be required while loading two neutron sources for each logging run. Mechanical design of the logging tool is simplified inasmuch as a provision for only one capsule in the sonde is necessary in practicing the invention. Loss or damage to the sonde might also lead to a more complicated neutron emitter recovery problem if it involved two neutron capsules rather than a single capsule with two emitters. The combined emitter arrangement exhibits further advantages in that the administrative task involved in multiple source accountability for health, safety and government regulatory purposes is reduced, and the need for an extra shielded transportation container on the logging truck is eliminated. In addition, it permits a reduction in the length of the sidewall skid, thus allowing the skid to moreclosely follow thec ontour of the borehole wall.

Preferably, a two-neutron energy emitter capsule suitable for use in connection with the invention comprises an intimate mixture of plutonium and lithium for low energy neutron production. This mixture is combined chemically, mechanically, or in any suitable manner, with another mixture of plutonium and beryllium which produces high energy neutrons.

Rather than intermix the two neutron emitters, two neutron sources 62 and 63 as shown in Fig. 4, can be segregated from each other by means of a partition 64 or the like that is secured within a capsule 65 which is suitably locked in place within the tool by an illustrative threaded number 66. The neutron-distance distribution established with a source of this sort, moreover, should not differ in essentials from that which is shown in Fig. 3. This segregation of the neutron emitters within the same capsule might also provide some further efficiencies if a source is returned for repair or chemical processing.

Detector separation from the two-neutron source capsule to provide the mudcake and mudcake-formation response that characterizes this invention can be determined in a manner that is similar to that which was described in connection with the two separate neutron source capsules that are shown in Fig. 1. For example, the mudcake neutron detector separation from the source can be optimized through position adjustment in response to measurements that are made in earth formations with known physical and mudcake properties. Hence, measurements are used to establish a separation which, on the average, provides the best mudcake data or definition. Similarly, the position of the longer-spaced mudcake and formation neutron detector also can be determined through this empirical method to provide the best average response in a range of commercially interesting types of earth formations. The same procedure can be used to determine the optimum relative strengths of the high-and-low-energy sources. This procedure shifts the ordinates of the two distribution curves of Fig. 3 relative to one another and assures that the supplementary detector (at B) detects principally neutrons emitted by the low energy source and the primary detector (at A) detects principally neutrons emitted by the high energy source.

Typical function former circuits of the sort described in connection with these embodiments of the invention can be found in standard reference texts. The book *Analog Computation* by Albert S. Jackson, McGraw-Hill Book Company, Inc., New York, 1961, for example, contains a number of circuit designs that are suitable for application to the invention. It should be noted, however, that the invention is not limited to analog computation techniques, but is applicable to any compatible data processing system, e.g., digital computation.

WHAT WE CLAIM IS:—

1. A method of investigating earth formations traversed by a borehole having solid matter along at least a portion of the wall thereof, comprising the steps of:

emitting neutrons of relatively high energy at successive levels in the borehole,

detecting radiations resulting from said

high energy neutrons at relatively long spacings from the levels at which they are emitted to produce signals functionally related to a characteristic of the earth formation,

emitting neutrons of relatively low fixed energy at successive levels in the borehole selected to obtain a slowing down length, in the solid matter before reaching thermal energy, that is of the order of magnitude of the typical thickness of the solid matter, and,

in response to radiation resulting from said low energy neutrons and detected at relatively short spacings from the levels at which said low energy neutrons are emitted, producing indications representing a correction of said formation characteristic to account for said solid matter.

2. A method according to claim 1 wherein the shorter spacings are selected for a substantially minimum response to radiation resulting from said high energy neutrons.

3. A method according to claim 1 wherein the low energy neutrons have an energy resulting in a slowing down length of about 3 to 10 cm.

4. A method according to claim 1, 2 or 3 wherein said high energy neutrons have an energy resulting in a slowing down length of about 10 to 30 centimeters.

5. A method according to any preceding claim wherein epithermal neutron radiation is detected at each of said spacings to obtain corrected indications of porosity.

6. A method according to any preceding claim, further comprising the step of combining said functionally related signals with said correction indications for producing corrected indications of porosity.

7. A method according to claim 6, further including the step of recording said corrected indications of porosity as a function of borehole depth.

8. A method according to any preceding claim, further including the step of recording indications of thickness of said solid matter as a function of borehole depth in response to said correction indications.

9. Apparatus for investigating earth formations traversed by a borehole having solid matter along at least a portion of the wall thereof, comprising:

a source of relatively high energy neutrons;

first detector means at a relatively long longitudinal spacing from said high energy source and responsive to radiation resulting from said high energy neutrons for producing first signals functionally related to a formation characteristic;

a source of fixed relatively low energy neutrons having a slowing down length before reaching thermal energy that is of the order of magnitude of a typical thickness of solid matter expected in boreholes to be investigated; and

second detector means at a relatively short longitudinal spacing from said low energy source and responsive to radiation resulting from said low energy neutrons for producing second signals functionally related to a parameter of said solid matter to provide correction for the disturbing effect of said solid matter on said first signals.

10. Apparatus according to claim 9 wherein said low energy source produces neutrons having an average energy in the range of about 25 to 240 KeV.

11. Apparatus according to claim 10 wherein said high energy source produces neutrons having an average energy of about 3 or 4 MeV.

12. Apparatus according to any of claims 9, 10 or 11 wherein the spacing between said second detector means and said high energy source is such as to produce substantially minimum response of said second detector means to radiation from said high energy source.

13. Apparatus according to any of claims 9 to 12, wherein the spacing between said high energy source and said first detector means is of about fifteen inches or more.

14. Apparatus according to any of claims 9 to 13, wherein said detector means are selectively responsive to epithermal neutrons.

15. Apparatus according to any of claims 9 to 14, further including circuit means for combining said first and second signals to produce corrected output indications of the formation characteristics.

16. Apparatus according to claim 15, further including means for recording said corrected indications of formation characteristics.

17. Apparatus according to claim 15 wherein said detector means are selectively responsive to epithermal neutrons and said corrected output indications are of porosity of the formation.

18. Apparatus according to claim 17, further including means for recording said porosity indications.

19. Apparatus according to claim 18 wherein said recording means is further responsive to said second signals for recording indications representative of a parameter of said solid matter as a function of borehole depth.

20. A method for investigating an earth formation traversed by a borehole, having a layer of solid material along at least a portion of the wall thereof, comprising:

deriving one measurement representative of the diffusion through this layer of material and the formation of neutrons having an initially relatively high energy,

deriving a second measurement primarily

representative of the diffusion through this layer of material of neutrons having an initially relatively low energy as compared to that of said high energy neutrons, and modifying said one measurement by combining it with said second measurement to produce one output measurement representative of a characteristic of the earth formation.

21. The method of claim 20 further comprising the step of recording said one output measurement.

22. The method of claim 20 further comprising the steps of producing a second output measurement functionally related to said second measurement which is representative of a parameter of said layer of material and recording said second output measurement together with said one output measurement.

23. The method of claim 21 further comprising the step of recording said second measurement as a representation of the disturbing influence of said layer of material on the measurement of said characteristic.

24. The method of claim 20 wherein said one and second measurements are representative of respective rates of detection of epithermal neutrons resulting from said high and low energy neutrons respectively and said one output measurement represents the porosity of the formation.

25. A method of investigating earth formations traversed by a borehole having a mudcake on at least a portion of the wall thereof, substantially as described hereinbefore with reference to and as illustrated in the accompanying drawings.

26. Apparatus for investigating earth formations traversed by a borehole having a mudcake on at least a portion of the wall thereof, substantially as described hereinbefore with reference to and as illustrated in the accompanying drawings.

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Chartered Patent Agent,
Agent for the Applicants.

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1366357 COMPLETE SPECIFICATION

3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

FIG.1.

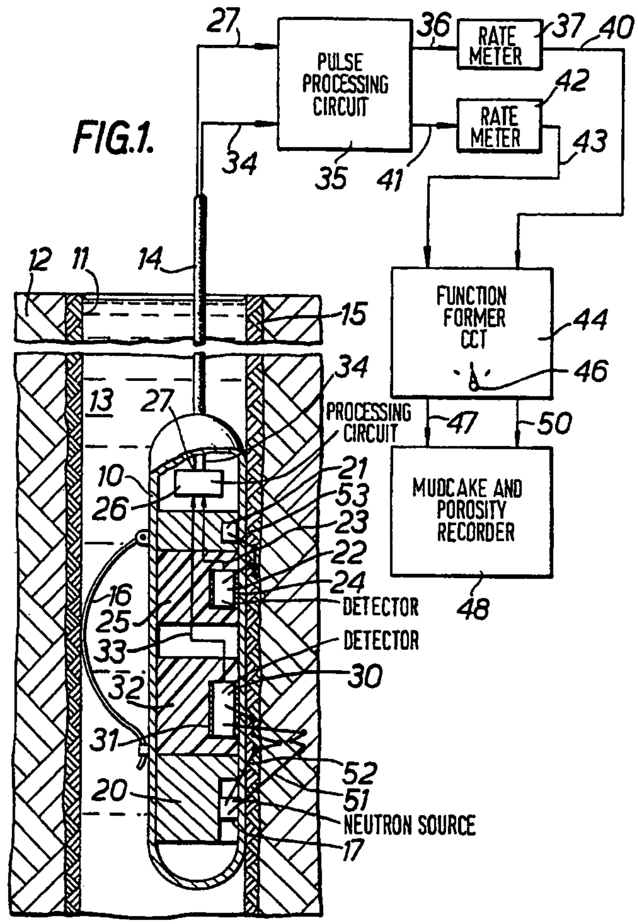


FIG.2.

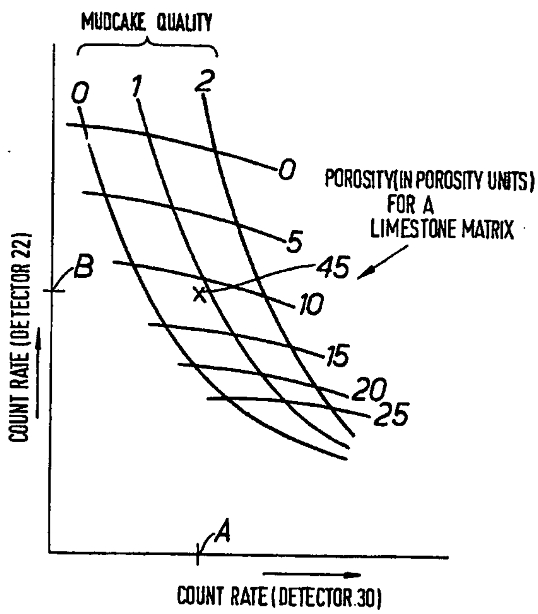

MUDCAKE QUALITY
0
1
2
0
5
45
10
15
20
25
POROSITY (IN POROSITY UNITS) FOR A LIMESTONE MATRIX
B
A
x
COUNT RATE (DETECTOR 22)
COUNT RATE (DETECTOR 30)

FIG. 3

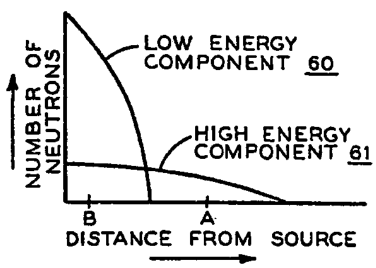
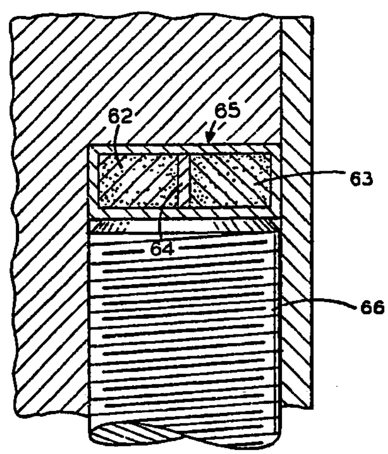

LOW ENERGY COMPONENT 60
HIGH ENERGY COMPONENT 61
NUMBER OF NEUTRONS
B
A
DISTANCE FROM SOURCE

FIG. 4


62
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63
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